

Improved Single-Crystal Superalloys Tailored for Hydrogen Service

Deborah D. Schmidt/EH23
205-544-4943

This research and development program is geared toward significantly improving fatigue properties of rocket engine components exposed to a high-pressure hydrogen environment, e.g., the space shuttle main engine turbine blades and nozzles. The ultimate goals are improved fatigue and fracture capability at the maximum debit condition (26 °C, 35 megaPascals of gaseous-hydrogen exposure) and improved, elevated, service-temperature cyclic properties with minimum impact on monotonic properties.

Current Rocketdyne and Pratt & Whitney high-pressure turbopump blade lives are limited by their low-cycle, high-cycle, and thermal-fatigue properties. Both turbopumps contain blades—either directionally solidified or single-crystal—which have microstructures not optimal for service-life extension. Certain microstructural defects, such as porosity and eutectic phase,^{1,2} limit fatigue life in both hydrogen-burning space shuttle main engines and air-breathing gas-turbine engines.

Removal of the eutectic phase has been accomplished in two candidate Pratt & Whitney alloys: 1482 and 1484. These were selected because their chemical compositions have wider heat-treating (solutionizing and diffusing) windows. The porosity was

removed by optimizing the hot isostatic pressing procedure such that recrystallization would not occur. Improved fatigue crack growth resistance was accomplished through development of a modified (“bimodal” or “duplex”) gamma-prime precipitate morphology. This approach was used because cracks tend to follow the path of least resistance.

Traditionally, gamma prime is precipitated by a discreet, ordered cuboidal morphology for optimal creep-rupture properties. Because gamma prime is stronger than the matrix, the cracks tend to propagate along the interface of the gamma-prime phase and the matrix. With this in mind, a bimodal gamma prime was precipitated with morphologies of enlarged and irregular shapes, as well as cuboidal gamma prime. This, in essence, forced the cracks to follow a more tortuous path, slowing their progression.³

All initial program goals have been met. Fatigue properties in hydrogen have been improved by a factor of 100 by the removal of the eutectic phase and porosity, and the crack growth rate has been reduced at least by a factor of 4. Enlargement of the data base is continuing by further strain-controlled fatigue tests and creep-rupture tests, with test data analysis also continuing.

If research and development results continue to be favorable, both of the eutectic-free, bimodal, gamma-prime alloys (1482 and 1484) will be candidates for flight certification for space shuttle main engine turbine blades and nozzles. Such microstructural improvements might also be considered for the next generation of propulsion systems.

Commercial research and development is currently underway to utilize the technology for the Department of Defense, the Department of Energy, and other applications. The commercialization focal point is to utilize the superalloys with improved microstructures for applications that require high strength at elevated service temperatures. Enhancements in thin rolled sheets for weight control is only one example.

¹Schmidt, D.D.; Alter, W.S.; Hamilton, W.D.; and Parr, R.A. August 1989. The Effects of Temperature Gradient and Growth Rate on the Morphology and Fatigue Properties of MAR-M246 (Hf), NASA TM-100374.

²Schmidt, et al. Directional Solidification of Superalloys. U.S. Patent Number 4,964,453.

³Biondo, C.M.; DeLuca, D.P.; Peters, B.J.; and Schmidt, D.D. 1994. The Influence of Thermal Processing and Microstructure on the Mechanical Properties of Single Crystals in Hydrogen. Advanced Earth-to-Orbit Propulsion Technology, NASA/MSFC Conference Publication 3282, 1:10-19.

Sponsor: Earth-to-Orbit Propulsion Technology

Industry Involvement: Pratt & Whitney

■■■■■